User Manual for the

SM200

Soil Moisture Sensor

SM200-UM-1.1

Delta-T Devices Ltd

Notices

Copyright

All parts of the SM200 design and documentation are the exclusive right of Delta-T Devices and covered under copyright law, © 2006. Patent(s) pending.

CE conformity

The SM200 product is CE compliant, conforming to EN61326:1997.

Design changes

Delta-T Devices Ltd reserves the right to change the designs and specifications of its products at any time without prior notice.

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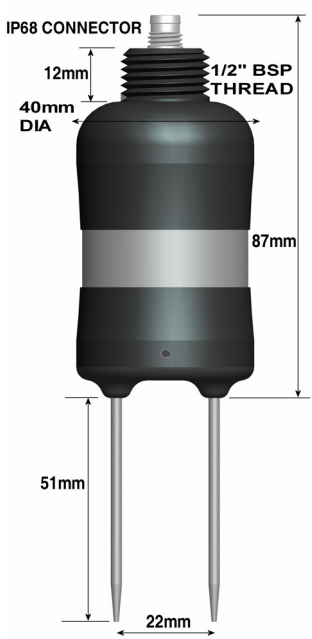
Introduction

Description

The *SM200* measures soil moisture content at a single location, sampling ~0.5 litres of soil (or other growing medium). It consists of a sealed plastic body, ~40mm diameter, attached to two sensing rods. The probe is fitted with a waterproof connector that is easily connected to extension cables.

When taking a reading, the probe rods are inserted directly into the soil.

The output from an SM200 is a simple analogue dc voltage. This output can be converted into soil moisture using the supplied general soil calibrations or the probe can be calibrated for specific soils.

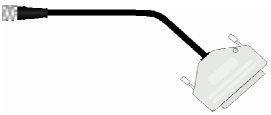


Features

- ± 3% scientific accuracy
- Low salinity sensitivity
- Excellent temperature stability
- Minimal soil disturbance
- Easy installation at depth in augered holes
- IP68 connector
- Rugged, weatherproof and buriable

Parts list

You consignment may have the following parts:

Part	Sales Code	Description
	SM200	SM200 soil moisture sensor fitted with M8 connector, in protective packing tube.
	- **(supplied with SM200)**	Quick Start Guide
	**SM2C/d-HH2**	1.1m cable for connecting SM200 to HH2 using 25-way D-connector
	SM2C/w-05	5m cable connects SM200 to data loggers. Terminates in bare wires.
	EXT/M8-05 **EXT/M8-10** **EXT/M8-25**	5, 10 and 25m extension cables. Terminates in IP68 in-line connector.
	SM-INRD1	1m insertion rod
	ML2-AG1-SL	45mm spiral auger 1.2m long

Care and Safety

- The rods of the SM200 are sharp in order to ease insertion. Care must be taken and handling precautions followed.

- Avoid touching the rods or exposing them to other sources of static damage. Keep the SM200 in its protective tube when not in use.

To prevent personal injury and damage to the probe always store and transport the SM200 in this protective tube

CAUTION
SHARP PINS

Handle with care

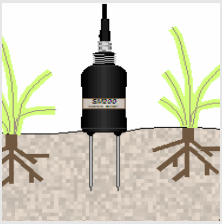
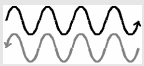
- Take care when attaching cables to ensure that the connectors are clean, undamaged and properly aligned before pushing the parts together.

- Screw together firmly to ensure the connection is water-tight. If the connector is damaged, apply a light smearing of silicon grease to maintain sealing.

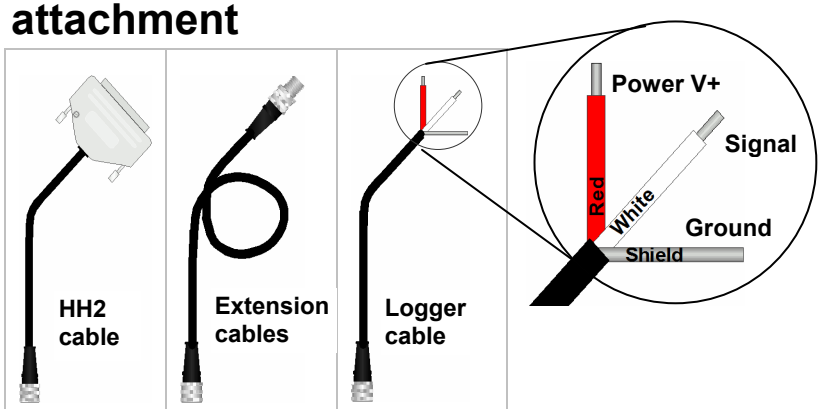
- Do not pull the SM200 out of the soil by its cable.

- If you feel strong resistance when inserting the SM200 into soil, it is likely you have encountered a stone. Stop pushing and re-insert at a new location.

How the SM200 works

	When power is applied to the *SM200*...
∿	...it creates a 100MHz waveform (similar to FM radio).
	The waveform is applied to a pair of stainless steel rods which transmit an electromagnetic field into the soil.
	The water content of the soil surrounding the rods...
ε	...dominates its **permittivity**. (A measure of a material's response to polarisation in an electromagnetic field. Water has a permittivity ≈ 81, compared to soil ≈ 4 and air ≈ 1)
	The permittivity of the soil has a strong influence on the applied field…
V_{out}	…which is detected by the SM200, resulting in a stable voltage output that…
Soil Moisture 22 %	...acts as a simple, sensitive measure of **soil moisture content**.

Cable attachment



1.1m	5m 10m 25m	5m

- If you plan to install the SM200 at depth using the insertion rod, pass the connector through the rod **before** attaching the cable.
- Take care when attaching cables to ensure that the connectors are clean, undamaged and properly aligned **before** pushing the parts together.
- Screw together firmly to ensure the connection is water-tight.
- Extension cables can be joined up to a recommended maximum of 55m.

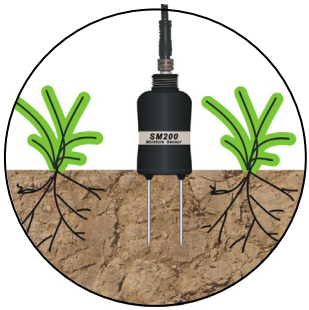
Cable functions

The SM200 is a single-ended sensor. The cables are assigned as follows:

Function	*Name*	*Colour*
Power to sensor	**Power V+**	Red
Sensor output +	**Signal**	White
Power V- Sensor output –	**Ground**	Shield (silver)

Installation

Surface installation and spot measurements



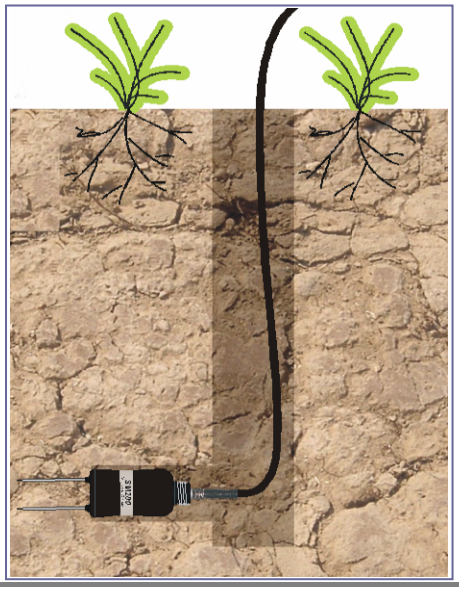
- Clear away any stones. Pre-form holes in very hard soils before insertion.
- Push the SM200 into the soil until the rods are fully inserted. Ensure good soil contact.
- If you feel strong resistance when inserting the SM200, you have probably hit a stone. Stop, and re-insert at a new location.

Installing at depth

- Auger a 45mm diameter hole. ~10° to vertical is recommended.
- Fit insertion rod to SM200 - remember to pass the cable through the insertion rod and fit the connector first.
- Push the SM200 into the soil until rods are fully inserted. Ensure good soil contact.
- Backfill around the insertion rod.

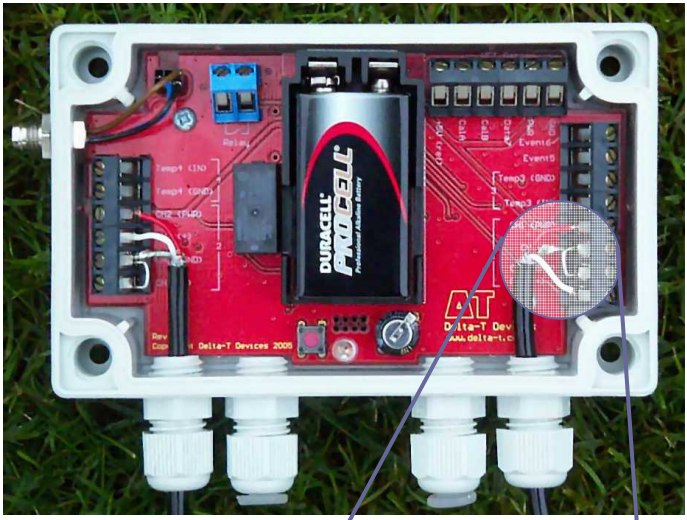
Alternatively

- Dig a trench, and install horizontally (see diagram).



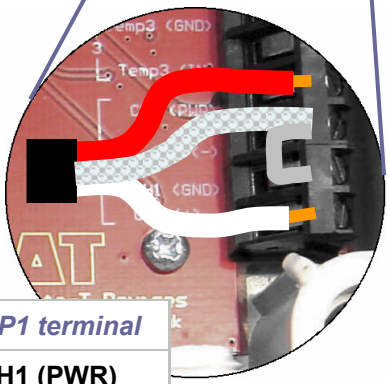
Logger connections and configuration

GP1



2 SM200s can be connected to each GP1, as shown in the photo.

The diagram and table illustrate the connections for Channel 1:

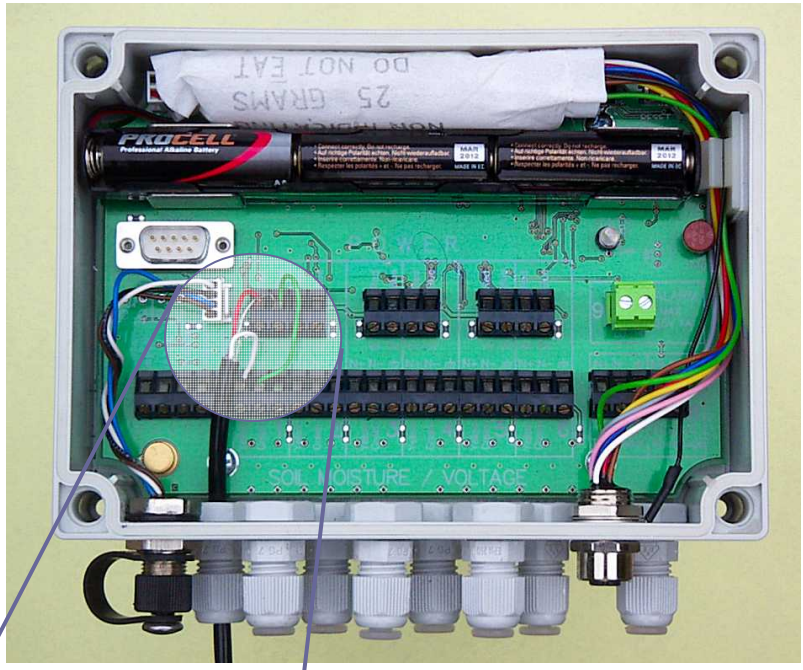


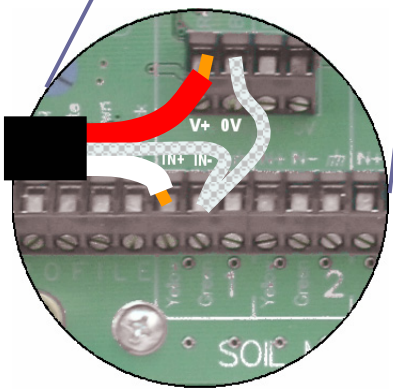
SM200 wiring	*Colour*	*GP1 terminal*
Power V+	Red	**CH1 (PWR)**
Signal	White	**CH1 (+)**
Ground	Shield	**CH1 (GND)** *and* **CH1 (-)**

Configure the GP1 by choosing “SM200” from the sensor menu in **DeltaLINK**-PC or Pocket **DeltaLINK**.

For configuration details see the ***GP1 Quick Start Guide***.

DL6





Up to 6 SM200s can be connected to each DL6.

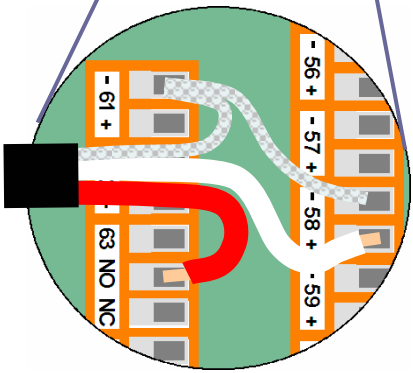
These details illustrate connection to Channel1:

SM200 wiring	*Colour*	*DL6 terminal*
Power V+	Red	**V+**
Signal	White	**IN+**
Ground	Shield	**IN-** *and* **0V**

Configure the DL6 by choosing “SM200” from the sensor menu in **DeltaLINK**-PC or Pocket **DeltaLINK**. For configuration details refer to the ***DL6 Quick Start Guide***.

DL2e

Configure the DL2e by choosing one of the SM200 sensor codes from the LS2Win sensor library, according to your soil type.



Up to 60 SM200s can be connected to each DL2e.

These details illustrate connection to Channel 58 using the LAC1 input card configured in 15-channel mode, and warm-up channel 63:

SM200 wiring	*Colour*	*DL2e terminal*
Power V+	Red	**63 NO**
Signal	White	**58+**
Ground	Shield	**58-** *and* **61-**

For configuration details see the ***DL2e User Documentation***.

Other data loggers

- The SM200 should be connected as a single-ended, powered sensor.
- Configure the logger input as a voltage sensor, approximately 0 to 1.0 volts corresponding to ~0 to 60% water content – see next section.
- The SM200 has been optimised for a 1 second warm-up period. It is recommended that the sensor is not powered continuously.
- Configure the logger to convert the SM200 readings into soil moisture using the polynomial or linearisation tables – see **Calibration**.

HH2 moisture meter

- Connect the SM200 to the HH2 meter.
- Press **Esc** to turn the meter on, and if necessary press again until the HH2 displays the start-up screen.
- Set the meter to read from an SM200:
  - Press **Set** and scroll down to the **Device** option.
  - Press **Set** again and scroll down to select SM200:

    ```
    Device:
     SM200
    ```

  - Press **Set** to confirm this choice.

- If you intend to store readings, it may be helpful to define each reading by setting a plot label and sample number – accessed by pressing **Set** and scrolling to the **Data** option.

- Press **Read** to take a reading (it takes about 2 seconds). You can choose different units from the **Display** option.

  ```
  SM200    Store?
  20.3%vol
  ```

- Press **Store** to save or **Esc** to discard the reading.
- Remove the SM200 and move to a new location...

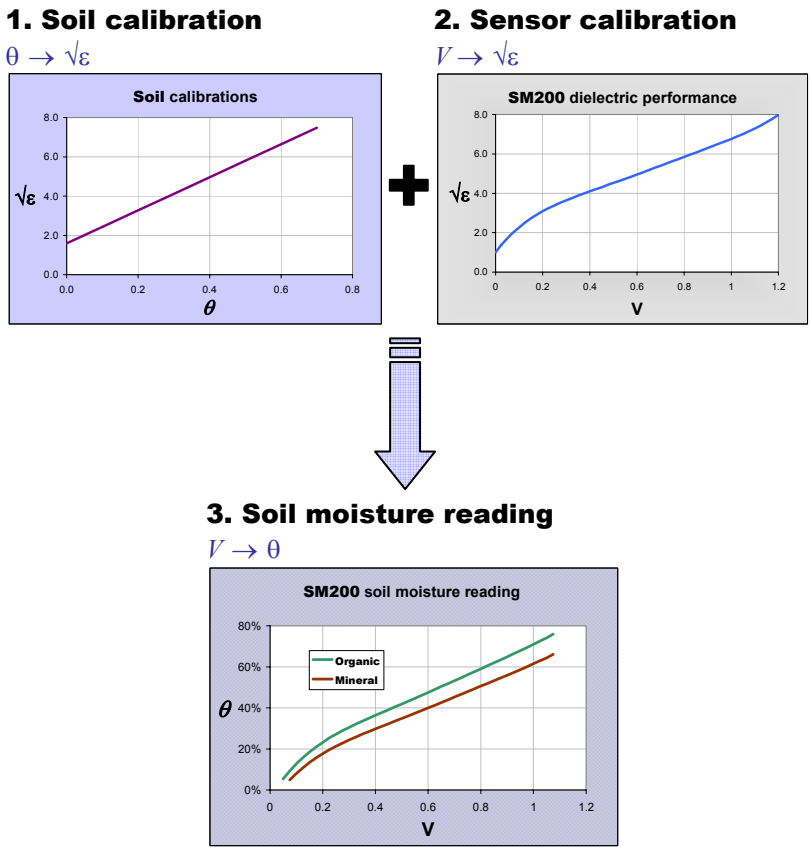
If you have saved data, connect your HH2 to a PC and run ***HH2Read*** to retrieve the readings.

Refer to the **HH2 User Manual** for further details.

Calibration

The SM200 is provided with general calibrations for **mineral** and **organic** soils which can be used to convert the output from the sensor directly into soil moisture when used with Delta-T loggers and the HH2 moisture meter. This section explains how these calibrations work, how to adapt them for other soils and how to provide calibrations for other data loggers.

The SM200 measures volumetric soil moisture, θ, by detecting the dielectric properties of the damp soil – the permittivity, ε, or more conveniently the **refractive index**, which is closely equivalent to $\sqrt{\varepsilon}$. The SM200 response is best understood in these stages:



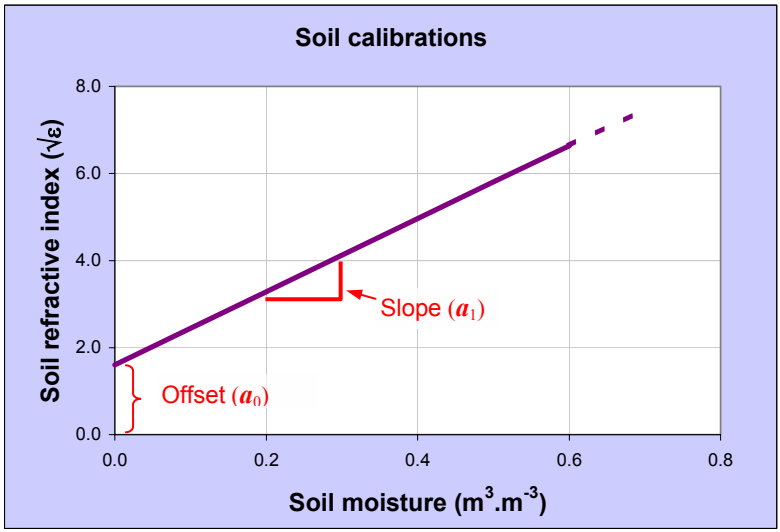
Soil calibration

Damp soil is essentially a mixture of soil particles, air and water, and together these components determine its dielectric properties, including the refractive index $\sqrt{\varepsilon}$. The refractive index of the mixture is approximated simply by adding the contributions from the individual components [ref 4.].

For a particular soil, the contribution from the soil particles can be assumed to be constant, so the refractive index measured by the SM200 is only affected by changes to the water content, θ. This relationship simplifies to:

$$\sqrt{\varepsilon} = a_0 + a_1 \cdot \theta$$

where the coefficients a_0 and a_1 conveniently parameterise the dielectric properties of soils.



Note that:

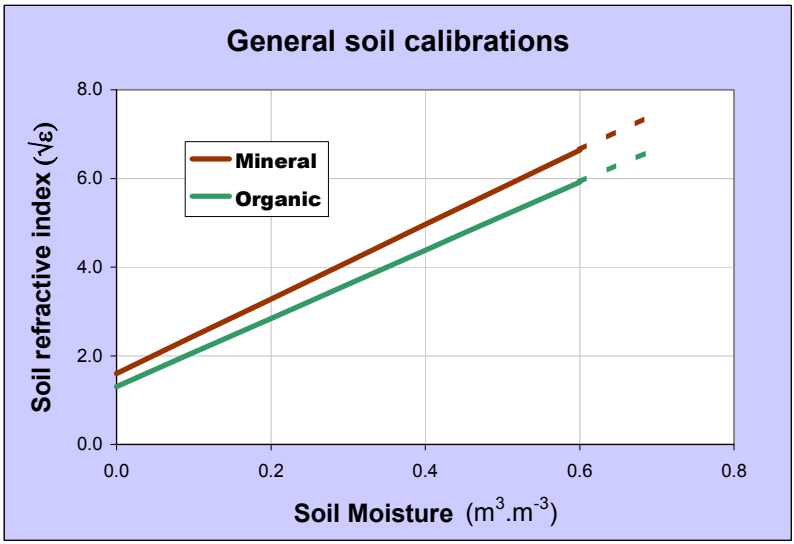
$a_0 = \sqrt{\varepsilon_{dry_soil}}$ is usually between 1.3 to 2.3

a_1 corresponds approximately to $\sqrt{\varepsilon_{water}} - 1$ and usually takes a value about 8.0. Real soil values for a_0 and a_1 can vary significantly from these guidelines when they are affected by other factors – in particular, bound water in clay soils may result in higher values of a_1.

General soil calibrations

Most soils can be characterised simply by choosing one of the two general calibrations we supply, one for mineral soils (predominantly sand, silt and clay) and one for organic soils (with a high organic matter content).

	a_0	a_1
Mineral soils	1.6	8.4
Organic soils	1.3	7.7



These values have been used to generate the polynomial conversions and linearisation tables in the **Soil moisture reading** section.

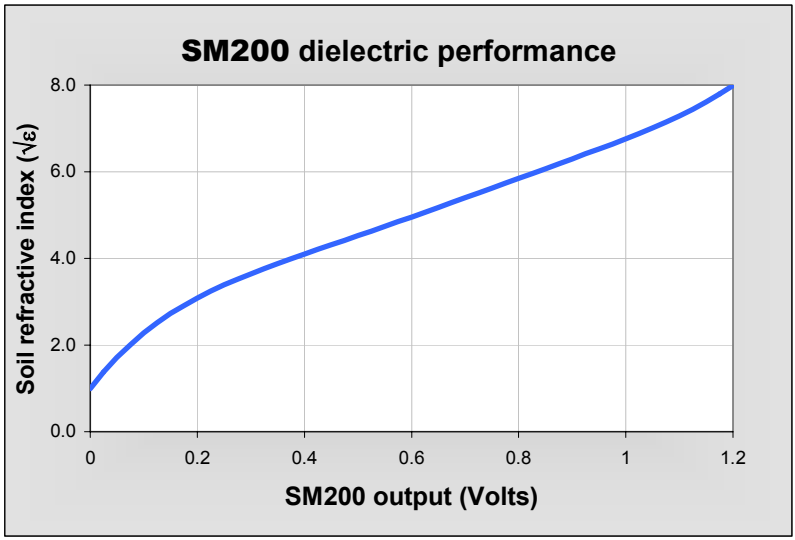
Soil-specific calibration

Instead of adopting these general calibrations, you may wish to determine specific calibration values of a_0 and a_1 for your soil. This procedure is fairly straightforward if you can get access to standard laboratory equipment and is described in detail in Appendix A.

Soil specific calibration can significantly improve the accuracy of individual readings - but make less of an improvement to readings where installation and sampling errors are high.

Sensor calibration

Each SM200 is individually adjusted to provide consistent dielectric performance:



This response can be approximated either by a polynomial or by a linearisation table:

Polynomial (use for SM200 readings from 0 to 1.1 Volts)

$$\sqrt{\varepsilon} = 1.0 + 16.103V - 38.725V^2 + 60.881V^3 - 46.032V^4 + 13.536V^5$$

where V is the SM200 output in Volts

Linearisation table (use for SM200 readings from 0 to 1.2 Volts)

V	$\sqrt{\varepsilon}$	V	$\sqrt{\varepsilon}$	V	$\sqrt{\varepsilon}$	V	$\sqrt{\varepsilon}$
0.000	1.011	0.150	2.729	0.400	4.102	1.100	7.290
0.030	1.453	0.180	2.956	0.600	4.956	1.150	7.610
0.060	1.842	0.220	3.218	0.820	5.939	1.200	7.982
0.090	2.179	0.260	3.446	0.960	6.571	1.220	8.205
0.120	2.473	0.310	3.701	1.040	6.960	1.800	9.000

Soil moisture reading

Polynomial conversion

Combining the **Soil calibrations** and **Sensor calibration** steps, the conversion equation becomes:

$$\theta = \frac{\left[1.0 + 16.103V - 38.725V^2 + 60.881V^3 - 46.032V^4 + 13.536V^5\right] - a_0}{a_1}$$

where a_0 and a_1 are the calibration coefficients.

For a generalised **mineral** soil this becomes:

$$\theta_{\text{mineral}} = -0.071 + 1.917V - 4.61V^2 + 7.248V^3 - 5.48V^4 + 1.611V^5$$

And for a generalised **organic** soil:

$$\theta_{organic} = -0.039 + 2.091V - 5.029V^2 + 7.907V^3 - 5.978V^4 + 1.758V^5$$

Linearisation table conversion

Alternatively, the conversion from SM200 reading (Volts) to soil moisture θ ($m^3.m^{-3}$ or %vol) can be accomplished by a linearisation table.

The following table lists the values used for the DL2e data logger:

Soil moisture	Mineral soil	Organic soil	Soil moisture	Mineral soil	Organic soil
%vol	Volts	Volts	%vol	Volts	Volts
-4	-2.090	-2.090	52	0.826	0.678
0	0.041	0.019	56	0.901	0.747
4	0.068	0.041	60	0.975	0.816
8	0.099	0.066	64	1.043	0.884
12	0.135	0.094	68	1.103	0.952
16	0.178	0.126	72	1.156	1.017
20	0.230	0.164	76	1.199	1.076
24	0.292	0.209	80	1.237	1.127
28	0.365	0.262	84	1.269	1.171
32	0.443	0.324	88	1.297	1.210
36	0.523	0.393	92	1.322	1.244
40	0.601	0.466	96	1.347	1.278
44	0.676	0.538	100	1.800	1.800
48	0.751	0.609	104	2.090	2.090

Troubleshooting

Always try to identify which part of the measurement system is the source of the difficulty. For the *SM200* this may fall into one of the following areas:

The measurement device

What equipment is being used to read the probe output?

- A Delta-T HH2 Moisture Meter
- A Delta-T data logger such as the GP1, DL6 or DL2e

Consult the user manuals or the on-line help for these devices and their related software. Try alternative types of equipment if you have them available.

Check that you are using an appropriate soil calibration and the correct conversion method – see **Calibration** section.

The SM200 itself

Try to isolate the problem into one of the following areas

- The SM200 or the connecting cable

Then try to narrow down the area further

- Mechanical problems faults, or damage
- Electrical or electronic problems or faults

Functional check

The following two simple checks can be used to establish whether your SM200 is functioning within expected bounds:

Air reading

Hold the SM200 away from other objects and take a reading using an HH2 meter, or other meter or logger. The reading should be 0 ±12mV when used with a 5m cable.

Finger reading

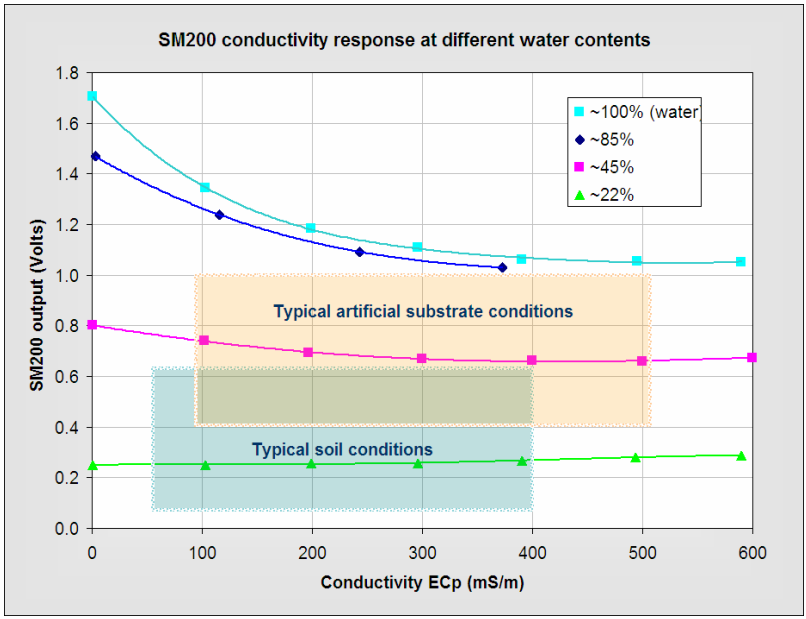
Hold the SM200 with your fingers wrapped closely (but carefully!) around the two metal rods and take a reading using an HH2 meter or other meter or logger. The reading should be between 500 to 750mV.

Specifications

		Range and Notes	
Accuracy*	± 3 %vol	0 to 50 %vol	
Salinity errors	± 3.5 %vol	0 to 40 %vol, over	50 to 500 $mS.m^{-1}$ (0.5 to 5 $dS.m^{-1}$)
Power requirement	5 to 14V 15mA typical	1 second warm-up recommended 200ms minimum	
Output signal	0 to 1.0V	Nominal 0 to 60 %vol	
Environmental sealing	IP68	Sensor buriable, sealed to IP68	
Operating range	-20 to +60°C	Readings in frozen soil are not meaningful	

** Accuracy figures apply to calibration soils and over 0 to 60°C.*
Percentages quoted as %vol are % volumetric water content.

Conductivity response

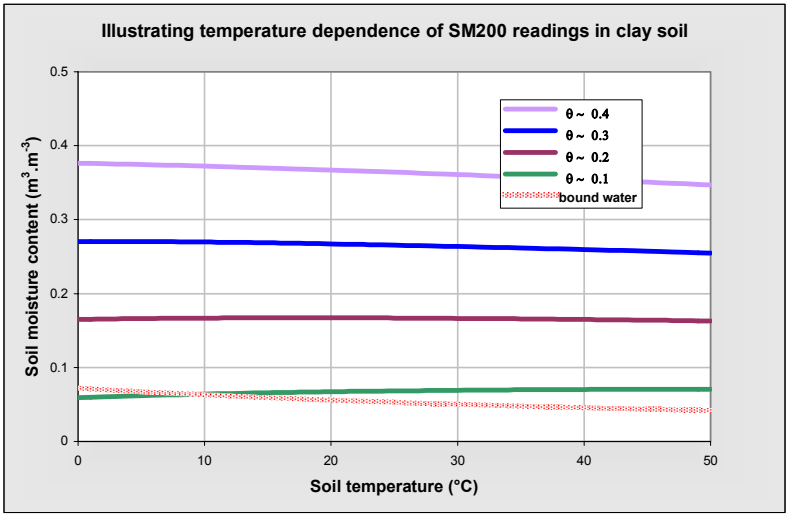


Temperature response

The SM200 temperature response in any particular soil will depend on a combination of effects:

- The SM200 electronics has a very low temperature sensitivity, and makes a negligible contribution to the overall sensitivity.
- The refractive index of water ($\sqrt{\varepsilon}$, see **Calibration** section) reduces as the temperature increases. This produces a negative temperature response particularly in soils or substrates with high water content.
- Water that is bound to the surface of soil particles has a much lower refractive index than free water. The percentage of bound water decreases with temperature and this produces a positive temperature response particularly in clay soils at lower water contents.

The last two effects partially offset each other, but in soil conditions where one or the other effect dominates, the SM200 will appear to have a significant temperature response. This illustration is based on the model in reference 7:



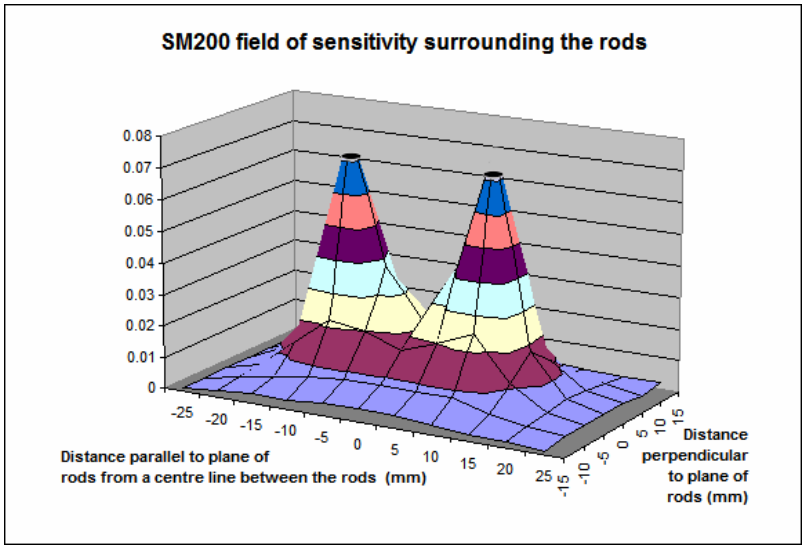
***Note**: ice has a quite different refractive index from water, so SM200 readings cannot be interpreted reliably when inserted into soil below 0°C.*

Sampling Volume

The SM200 is most sensitive to signals very close to the two rods, but a small proportion of the signal reaches up to 50mm from the rods. For best accuracy we recommend taking readings in at least 0.5 litres of soil, preferably 1.0 litre.

SM200s may interact if they are placed too close together – they should be separated by at least 100mm.

The sensitivity field for an SM200 inserted in water has been tested as shown in this figure (the vertical scale is in arbitrary units):



Electromagnetic Compatibility (EMC)

General information

SM200 is a Class A product, intended for operation in non-residential environments.

Only use cables and accessories authorised by Delta-T (sensor cables from other sources for example can adversely affect product performance and affect quality of results).

If possible route cables along the soil surface or bury them – this also reduces possible trip hazard and animal damage.

Do not modify the product or its supplied accessories.

Regulatory information

Europe

SM200 has been assessed for CE compliance under the European Union EMC directive 89/336/EEC and conforms to the appropriate standards, EN61326 (1997), providing the product is used as described in this manual. Use of non Delta-T cables and accessories may invalidate this.

FCC compliance (USA)

This device complies with part 15 of the FCC Rules. Operation is subject to the following conditions:

1. This device may not cause harmful interference
2. This device must accept any interference received, including interference that may cause undesired operation

Note: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his/her own expense.

Modifications not expressly approved by the manufacturer could void the user's authority to operate the equipment under FCC rules

Definitions

Volumetric Soil Moisture Content is defined as

$$\theta_V = \frac{V_W}{V_S}$$

where V_W is the volume of water contained in the sample and V_S is the total volume of the soil sample.

The preferred units for this ratio are **$m^3.m^{-3}$**, though **%vol** is frequently used.

Soil Moisture Content varies from approx. 0.02 $m^3.m^{-3}$ for sandy soils at the permanent wilting point, through approx. 0.4 $m^3.m^{-3}$ for clay soils at their field capacity, up to values as high as 0.85 $m^3.m^{-3}$ in saturated peat soils.

Gravimetric Soil Moisture Content is defined as

$$\theta_G = \frac{M_W}{M_S} g.g^{-1}$$

*where M_W is the mass of water in the sample, and M_S is the total mass of the **dry** sample.*

To convert from volumetric to gravimetric water content, use the equation

$$\theta_G = \theta_V \times \frac{\rho_W}{\rho_S}$$

where ρ_W is the density of water (= 1g.cm^{-3}), and ρ_S is the bulk density of the sample ($\frac{M_S}{V_S}$).

Organic and Mineral soil definitions:

The general calibrations have been optimised to cover a wide range of soil types, based on the following definitions:

Soil type	optimised around organic content:	use for organic contents:	bulk density range: (g.cm^{-3})	use for bulk densities: (g.cm^{-3})
Mineral	~ 1 %C	< 7 %C	1.25 - 1.5	> 1.0
Organic	~ 40 %C	> 7 %C	0.2 - 0.7	< 1.0

Salinity

The preferred SI units for ionic conductivity are **$mS.m^{-1}$** (where S is Siemens, the unit of electric conductance = ohm^{-1}).

The following conversions apply:

1 $mS.m^{-1}$ = 0.01 $dS.m^{-1}$

= 0.01 $mS.cm^{-1}$

= 10 $\mu S.cm^{-1}$

Soil salinity is also partitioned into the following descriptive categories:

non-saline	0 - 200	$mS.m^{-1}$
slightly saline	200 - 400	$mS.m^{-1}$
moderately saline	400 - 800	$mS.m^{-1}$
strongly saline	800 - 1600	$mS.m^{-1}$
extremely saline	> 1600	$mS.m^{-1}$

References

1. Gaskin, G.J. and J.D. Miller, 1996
   Measurement of soil water content using a simplified impedance measuring technique.
   J. Agr. Engng Res **63**, 153-160

2. Topp, G.C., J. L. Davis and A. P Annan 1980
   Electromagnetic determination of soil water content.
   Water Resour. Res **16**(3) 574-582

3. Whalley, W.R. 1993
   Considerations on the use of time-domain reflectometry (TDR) for measuring soil moisture content.
   Journal of Soil Sci. **44**, 1-9

4. White, I., J.H. Knight, S.J. Zegelin, and Topp, G.C. 1994
   Comments on 'Considerations on the use of time-domain reflectometry (TDR) for measuring soil water content' by W R Whalley
   Journal of Soil Sci. **45**, 503-508

5. Roth, C.H., M.A. Malicki, and R. Plagge, 1992
   Empirical evaluation of the relationship between soil dielectric constant and volumetric water content as the basis for calibrating soil moisture measurements.
   Journal of Soil Sci. **43**, 1-13

6. Knight, J.H. 1992
   Sensitivity of Time Domain Reflectometry measurements to lateral variations in soil water content.
   Water Resour. Res., **28**, 2345-2352

7. Or, D. and J.M. Wraith 1999
   Temperature effects on soil bulk dielectric permittivity measured by time domain reflectometry: A physical model.
   Water Resour Res., **35**, 371-383

Technical Support

Terms and Conditions of Sale

Our Conditions of Sale (ref: COND: 1/00) set out Delta-T's legal obligations on these matters. The following paragraphs summarise Delta-T's position but reference should always be made to the exact terms of our Conditions of Sale, which will prevail over the following explanation.

Delta-T warrants that the goods will be free from defects arising out of the materials used or poor workmanship for a period of **twelve months** from the date of delivery.

Delta-T shall be under no liability in respect of any defect arising from fair wear and tear and the warranty does not cover damage through misuse or inexpert servicing, or other circumstances beyond our control.

If the buyer experiences problems with the goods they shall notify Delta-T (or Delta-T's local distributor) as soon as they become aware of such problem.

Delta-T may rectify the problem by supplying replacement parts free of charge, or by repairing the goods free of charge at Delta-T's premises in the UK, during the warranty period.

If Delta-T requires that goods under warranty be returned to them from overseas for repair, Delta-T shall not be liable for the cost of carriage or for customs clearance in respect of such goods. However, we much prefer to have such returns discussed with us in advance and we may, at our discretion, waive these charges.

Delta-T shall not be liable to supply products free of charge or repair any goods where the products or goods in question have been discontinued or have become obsolete, although Delta-T will endeavour to remedy the buyer's problem.

Delta-T shall not be liable to the buyer for any consequential loss, damage or compensation whatsoever (whether caused by the negligence of the Delta-T, our employees or distributors or otherwise) which arise from the supply of the goods and/or services, or their use or resale by the buyer.

Delta-T shall not be liable to the buyer by reason of any delay or failure to perform our obligations in relation to the goods and/or services, if the delay or failure was due to any cause beyond the Delta-T's reasonable control.

Service and Spares

Users in countries that have a Delta-T Distributor or Technical Representative should contact them in the first instance.

Spare parts for our own instruments can be supplied from our works. These can normally be despatched within a few working days of receiving an order.

Spare parts and accessories for sensors or other products not manufactured by Delta-T may have to be obtained from our supplier and a certain amount of additional delay is inevitable.

No goods or equipment should be returned to Delta-T without first obtaining the agreement of Delta-T or our distributor.

On receipt at Delta-T, the goods will be inspected and the user informed of the likely cost and delay. We normally expect to complete repairs within a few working days of receiving the equipment. However, if the equipment has to be forwarded to our original supplier for specialist repairs or recalibration, additional delays of a few weeks may be expected.

Technical Support

Technical Support is available on Delta-T products and systems. Users in countries that have a Delta-T Distributor or Technical Representative should contact them in the first instance.

Technical Support questions received by Delta-T will be handled by our Tech Support team. Your initial enquiry will be acknowledged immediately with a “T number” and an estimate of time for a detailed reply. Make sure to quote our T number subsequently so that we can easily trace any earlier correspondence.

In your enquiry, always quote instrument serial numbers, software version numbers, and the approximate date and source of purchase where these are relevant.

Contact details:

Tech Support Team
Delta-T Devices Ltd
128 Low Road, Burwell, Cambridge CB5 0EJ, U.K.
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Soil-specific Calibration

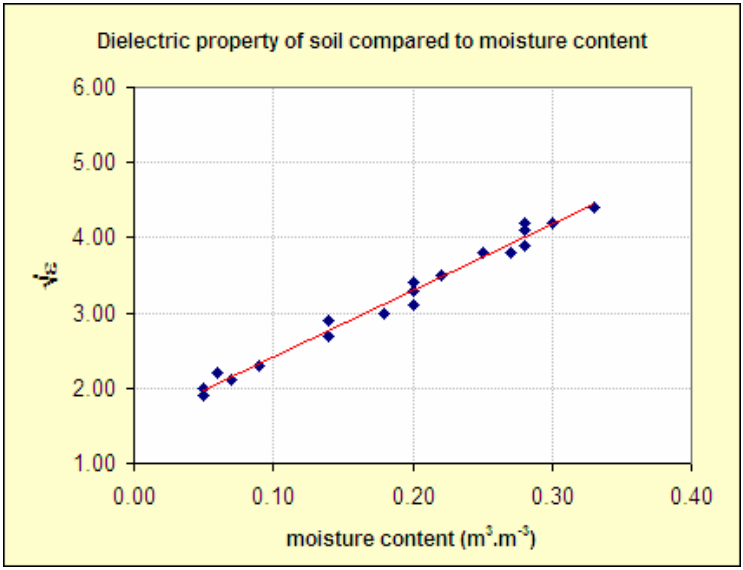
This note provides details of 2 techniques for generating soil-specific calibrations:

1. Laboratory calibration for substrates* and non-clay soils
2. Laboratory calibration for clay soils

* *We use the term substrate to refer to any artificial growing medium.*

Underlying principle

Soil moisture content (θ) is proportional to the refractive index of the soil ($\sqrt{\varepsilon}$) as measured by the *SM200* (see **Calibration** section).



The goal of calibration is to generate two coefficients (a_0, a_1) which can be used in a linear equation to convert probe readings into soil moisture:

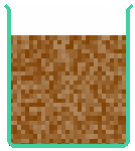
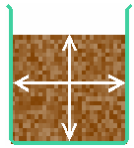
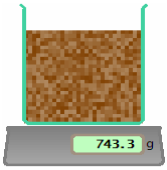
$$\sqrt{\varepsilon} = a_0 + a_1 \times \theta$$

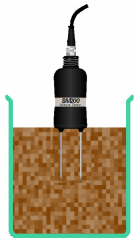
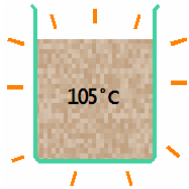
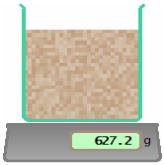
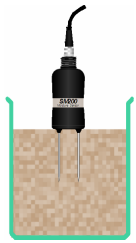
Laboratory calibration for non-clay soils

This is the easiest technique, but it's not suitable for soils that shrink or become very hard when dry.

Equipment you will need:

- SM200 and meter
- Soil corer (if doing a calibration for a cohesive soil rather than sand or a substrate)
- Heat-resistant beaker (≥ 0.5 litre)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven (for mineral soils or substrates)

Process	*Notes and example*
	Collect a damp sample of the soil or substrate. This sample needs to be unchanged from its in-situ density, to be ≥ 0.5 litre, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. For cohesive soils this is most easily done with a soil-corer. Sandy soils can be poured into the beaker, but you should take the subsequent measurements immediately, as the water will quickly begin to drain to the bottom of the beaker. Compressible soils and composts often require measurement of the in-situ density and then need to be carefully reconstituted at that density within the beaker.
	Measure the volume occupied by the sample. ***L_s = 463.5ml***
	Weigh the sample, including the beaker. ***W_w = 743.3g***

	Insert SM200 into the sample and record its output in Volts. **V_w = 0.350V**
	Dry the sample thoroughly. With mineral soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity). For organic soils and composts it's usual to air-dry the sample to avoid burning off any volatile factions.
	Weigh the dry sample in the beaker. **W_0 = 627.2g**
	Re-insert the SM200 into the dry sample and record this reading. **V_0 = 0.051V**
Calculate a_0	For the SM200, $\sqrt{\varepsilon} = 1.0 + 16.103V - 38.725V^2 + 60.881V^3 - 46.032V^4 + 13.536V^5$ In the dry soil $V = V_0$ = 0.051 Volts, and substituting this value into the above equation gives $\sqrt{\varepsilon_0} = 1.73$ Since θ_0 = 0, this is the value needed for a_0 **a_0 = 1.73**
Calculate θ_w	The water content of the wet soil, θ_w, can be calculated from the weight of water lost during drying, ($W_w - W_0$) and its volume, L_s: $\theta_w = (W_w - W_0)/L_s = (743.3 - 627.2)/463.5 = 0.25$

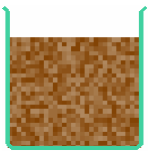
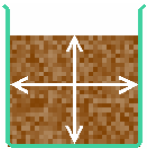
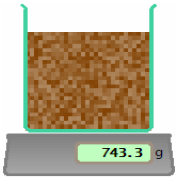
	θ_w = 0.25
Calculate a_1	In the wet soil $V = V_w$ = 0.350 Volts and substituting gives $\sqrt{\varepsilon_w} = 3.88$ Finally $a_1 = \left(\sqrt{\varepsilon_w} - \sqrt{\varepsilon_0}\right) / \left(\theta_w - \theta_0\right) = (3.88 - 1.73) / (0.25 - 0) = 8.60$ **a_1 = 8.60**

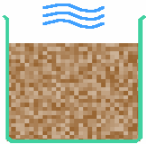
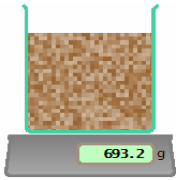
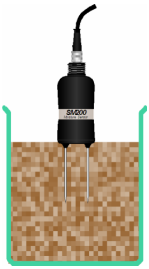
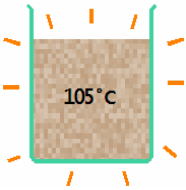
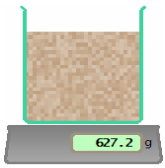
Laboratory calibration for clay soils

This technique is adapted to avoid the near-impossibility of inserting the SM200 into completely dry clay soil. It requires taking measurements at 2 significantly different, but still damp, moisture levels.

Equipment you will need:

- SM200 and meter
- Soil corer
- Heat-resistant beaker (≥ 500ml)
- Weighing balance (accurate to < 1g)
- Temperature controlled oven

Process	*Notes and example*
	Collect a wet sample of the clay soil: 25 to 30% water content would be ideal. This sample needs to be unchanged from its in-situ density, to be ≥ 500ml, to have the correct dimensions to fit the beaker, and to be generally uniform in water content. This is most easily done with soil-corer.
	Measure the volume occupied by the sample. ***L_s = 463.5ml***
	Weigh the wet sample, including the beaker. ***W_w = 743.3g***

	Insert SM200 into the wet sample and record its output in Volts. $V_w = 0.349V$
	Dry the sample until still moist, ~15% water content. Gentle warming can be used to accelerate the process, but take care not to over-dry in places, and allow time for the water content to equilibrate throughout the sample before taking a reading.
	Reweigh. $W_m = 693.2g$
	Re-measure with the SM200. $V_m = 0.180V$
	Dry the sample thoroughly. With mineral soils this is usually achieved by keeping it in the oven at 105°C for several hours or days (the time required depends on the sample size and porosity).
	Weigh the dry sample in the beaker. $W_0 = 627.2g$

Calculations	Substituting in the SM200 equation $\sqrt{\varepsilon} = 1.0 + 16.103V - 38.725V^2 + 60.881V^3 - 46.032V^4 + 13.536V^5$ provides two dielectric values, $\sqrt{\varepsilon_w}$ and $\sqrt{\varepsilon_m}$, at two known water contents, θ_w and θ_m
For the wet soil	Substituting V_w = 0.349 gives $\sqrt{\varepsilon_w} = 3.88 = a_0 + a_1 \cdot \theta_w$ for $\theta_w = (743.3 - 627.2)/463.5 = 0.25$
For the moist soil	Substituting V_m = 0.180 gives $\sqrt{\varepsilon_m} = 2.95 = a_0 + a_1 \cdot \theta_m$ For $\theta_m = (693.2 - 627.2)/463.5 = 0.14$
Calculate a_1	Then $a_1 = \left(\sqrt{\varepsilon_w} - \sqrt{\varepsilon_m}\right)/(\theta_w - \theta_m) = 8.56$ **a_1 = 8.56**
Calculate a_0	and $a_0 = \sqrt{\varepsilon_w} - (a_1 \cdot \theta_w) = 1.73$ **a_0 = 1.73**

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